Group 7:
Bijay Karki,
Vladislav Zakatov,
Himanshu Hooda

Recovery and stress meter development

Project Report

Metropolia University of Applied Sciences
Bachelor’s Degree in Engineering
Information Technology
7.5.2023 (v3.0)

Abstract

This project aimed to develop an embedded device capable of measuring heart rate and heart rate variability using photoplethysmography (PPG) and a Raspberry Pi Pico W microcontroller. The device was successfully built and tested, showcasing its ability to detect peaks, perform local HR and HRV calculations, and display results on an OLED screen. Additionally, the device can connect to Kubios Cloud for more in-depth HRV analysis. An intuitive navigation interface, designed with a rotary encoder, allows users to access various functionalities and options. The project's success demonstrates its potential for further development, optimization, and applications in the field of health monitoring and personal wellness.

Version history

Ver	Description	Date	Author(s)
1.0	Initial version of the project report was created based on the document template provided.	9.4.2023	Bijay Karki, Vladislav Zakatov Himanshu Hooda
2.0	The second version of the project report was created based on the previous (1.0) version, while comprehensive update and incorporating feedback, additional research, and refined methodology took place.	23.4.2023	Bijay Karki, Vladislav Zakatov Himanshu Hooda
3.0	The final version of the project report was created based on the previous (2.0) version, features key refinements by addressing feedback, optimizing analysis, and refining methodology. It also covers testing outcomes, PPI algorithm validation, and concise study conclusions.	7.5.2023	Bijay Karki, Vladislav Zakatov Himanshu Hooda

Table of Contents

1 Introduction

The field of health and wellness has seen rapid technical advancements in recent years, with technology playing a significant role in providing innovative solutions for everyday challenges. The following report outlines the development of a recovery and stress meter as part of the Hardware 2 course for first-year ICT engineering students at Metropolia University of Applied Sciences. The project aims to create a proof-of-concept device that can monitor and analyze recovery and stress levels based on Heart Rate Variability (HRV) using non-invasive optical sensors. (Metropolia University of Applied Sciences, 2023).

The motivation behind this project is to provide an accessible and easy-to-use tool for individuals and healthcare professionals to monitor stress and recovery levels in various settings such as homes, offices, and clinics. By enabling better understanding and management of stress and recovery, the project aims to contribute to overall health and wellbeing, as well as to satisfy and reach the study goals.

The project is divided into two phases. The first phase, that was completed by the end of the third study period, was focused on preliminary project planning, including building a project plan and familiarizing the team with the hardware components. The second phase, completed by the end of the fourth study period, was focused on implementing the proof-of-concept device and achieving the desired outcomes.

This report is structured into five main chapters. Chapter 1 provides a brief introduction to the project, its topic, goals, and motivation. Chapter 2 delves into the theoretical background of the project. Chapter 3 details the methods and materials employed during the project's development. Chapter 4 explains the implementation methods used to bring the project to fruition. Lastly, Chapter 5 presents the conclusions and highlights the key findings of the project.

In addition, the following report workload was shared across team members as follows:

Table 1. Report workload across team members.

Task(s)	Responsible team member
Chapter 1: Introduction Chapter 5: Conclusions Report formatting	Vladislav Zakatov
Chapter 3: Methods and Material Chapter 4.2: Heart rate algorithms Chapter 4.3: Implemented algorithm	Bijay Karki
Chapter 2: Theoretical Background Chapter 4.1: Pulse detection	Himanshu Hooda

2 Theoretical Background

The Theoretical Background section delves into the fundamental concepts and principles related to heart rate and heart rate variability, as well as the photoplethysmography (PPG) technique. This section provides a comprehensive understanding of the scientific context and framework, which lays the foundation for the project's development, design, and implementation.

2.1 Heart Rate Variability and Peak Detection

Heart rate (HR) is the number of heart beats per minute (bpm). Heart rate variability is the variation in time between two consecutive heartbeats or consecutive inter-beat-intervals (RR intervals). Terms which can be used for HRV are:

- RR interval (RRI) variability, where R corresponds to the peak of QRS-complex of electrocardiography (ECG), and
- Peak-to-Peak interval, if the HRV is measured optically (Used for the project) Example PPG signal is show in Figure 1.

For the project, peak-to-peak (PPI) interval was taken for the HRV analysis due to the kind of Hardware implemented into the project (photoplethysmography sensor). Variation in PPI can determine different aspects of a person’s health and heart condition. This can include analysis of both sympathetic and parasympathetic nervous system activity which are branches of the autonomic nervous system (ANS) and involved in the regulation of HR. Parasympathetic nervous system (PNS) activity (vagal stimulation) is known to decrease heart rate and increase heart rate variability. The sympathetic nervous system (SNS) activity has the opposite effect on heart rate and heart rate variability, i.e., it increases HR and decreases HRV. The sympathetic nervous system, also known as the "fight or flight" response, increases heart rate and prepares the body for physical activity or stress. On the other hand, the parasympathetic nervous system, also known as the "rest and digest" response, slows down the heart rate and promotes relaxation and recovery. Therefore, HR is the lowest and HRV is highest when we are at rest and fully recovered.

The interpretation of the PNS index is straightforward:

- A PNS index value of zero means that the three parameters reflecting parasympathetic activity are on average equal to the normal population average.
- A positive PNS index value tells how many SDs above the normal population average the parameter values are.
- A negative value tells how many SDs below the normal population average the parameter values are.
- In rest, the PNS index is typically (with 95% of population) between 2 and +2, i.e., within 2SD of the normal population distribution.
- During stress or during high intensity exercise much lower PNS index values can be expected.

The interpretation of the SNS index is similar to PNS index.

- A SNS index value of zero means that the three parameters reflecting sympathetic activity are on average equal to the normal population average.
- A positive SNS index value tells how many SDs above the normal population average the parameter values are.
- A negative value tells how many SDs below the normal population average the parameter values are.
- During stress or high intensity exercise SNS index can have values as high as 5 35.

BPM can be affected by several factors ranging from physical aspects to mental aspects. Intake of substances and hormonal change can also contribute to the variability of the heart. A heart rate of 60-100 BMP can be considered normal while 40-60 during sleep can be taken as normal value (Edward et al. 2022). According to Edward et al. (2022) normal range can be different for different individuals as the heart rate is variable and can be affected by different factors as

- Age
- Fitness and activity levels
- Being a smoker
- Having cardiovascular disease, high cholesterol or diabetes
- Air temperature
- Body position (standing up or lying down, for example)
- Emotions
- Body size and more

A PPG signal is used for detecting Peak-to-peak interval of the heart beats. PPI can be found through 3 different methods:

- Finding peaks through rising edge of the signal
- Finding positive peaks by slope inspection
- Finding negative peaks

Accurate detection of pulse or beats per minute is an integral part in the working of the device and a critical section to the project. Pulse detection is calculated through peak intervals as can be seen from example Figure 1.

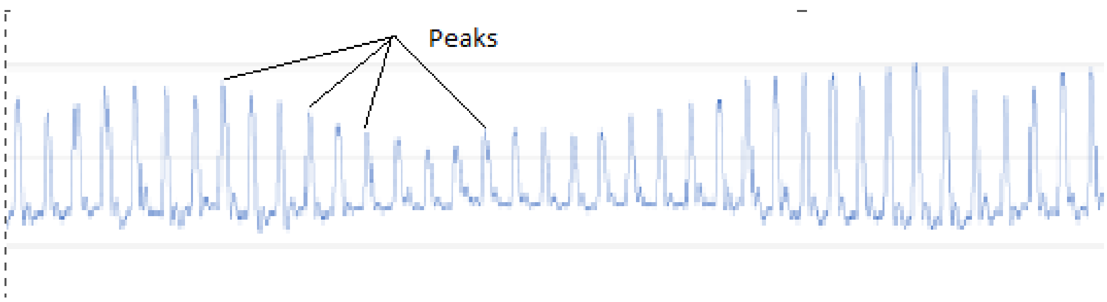


Figure 1. Pulse detection calculated through peak intervals.

Each peak represents a beating of the heart and the difference between two consecutive beats/peaks can determine peak to peak interval which then can be used to calculate beats per minute.

Peaks can be observed from the plotted graph of integer values received from the ADC converter. However, finding peaks with accuracy i.e., without false peak detection and missing vital peaks requires designing an algorithm that accurately detects the successive peaks without any missing values or including false peak which do not resemble a heartbeat pattern.

Peaks can be detected through several methods or combination of methods which will be discussed further. Selection of the most appropriate method and it's reasoning as to why this method has been chosen will be discussed in further sections in detail along with the algorithm itself.

2.2 Methods of Pulse detection

2.2.1 Finding rising edges

Peak intervals can be detected through taking a point on the rising edge of the graph above a certain threshold as shown in Figure 2. The important factor to take into consideration in any of the methods discussed hereafter is the value of threshold.

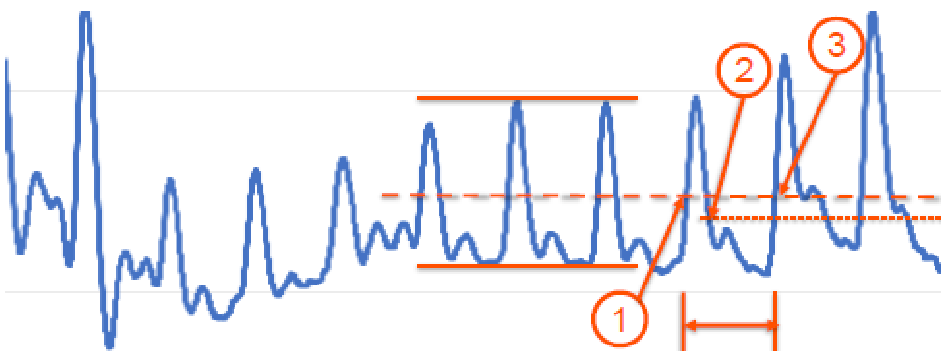


Figure 2. Peak intervals be detected through taking a point on the rising edge of the graph above a certain threshold.

Threshold can be calculated in variety of ways, however the important consideration to note is that the value of threshold should not be too high, so it excludes the lower amplitude actual peaks or not be too low to include false peaks which do not resemble the heartbeat pattern and therefore provides incorrect or false values for calculating beats per minute.

Once the threshold value is defined for a set of sample data, rising edge can be deducted by sample number which comes directly after the threshold value as can be noted from Figure 2**.** Once the sample number is noted and stored, the objective is to find the next consecutive rising edge from the sample data.

When the two consecutive rising edges are deducted from the sample data, the difference is calculated which is the number of samples between the two rising edges. The calculated number of samples is multiplied with frequency to deduce peak to peak interval or PPI.

PPI = n * frequency – (equation 1)

Once we have the PPI value, we can conveniently ascertain the beats per minute through equation 2.

BMP = 60/PPI – (equation 2)

2.2.2 Finding positive peaks

Peaks can be deducted by taking the highest value from the sample data between the rising and falling points of the threshold line. This can be observed from Figure 3. When two consecutive positive peaks are found in the sample data, the difference is calculated to ascertain PPI and hence forth BMP as defined in equations 1 and 2.

Figure 3. Peaks detection.

The flow chart for finding peaks from the positive integer values from ADC can be seen from Figure 4. The sample value which is over the threshold is then compared with the maximum value and if the sample value is greater than maximum, the sample number is stored as current peak. Once the two consecutive sample numbers with maximum values are identified by the same process, the difference between the two is calculated to deduct PPI.

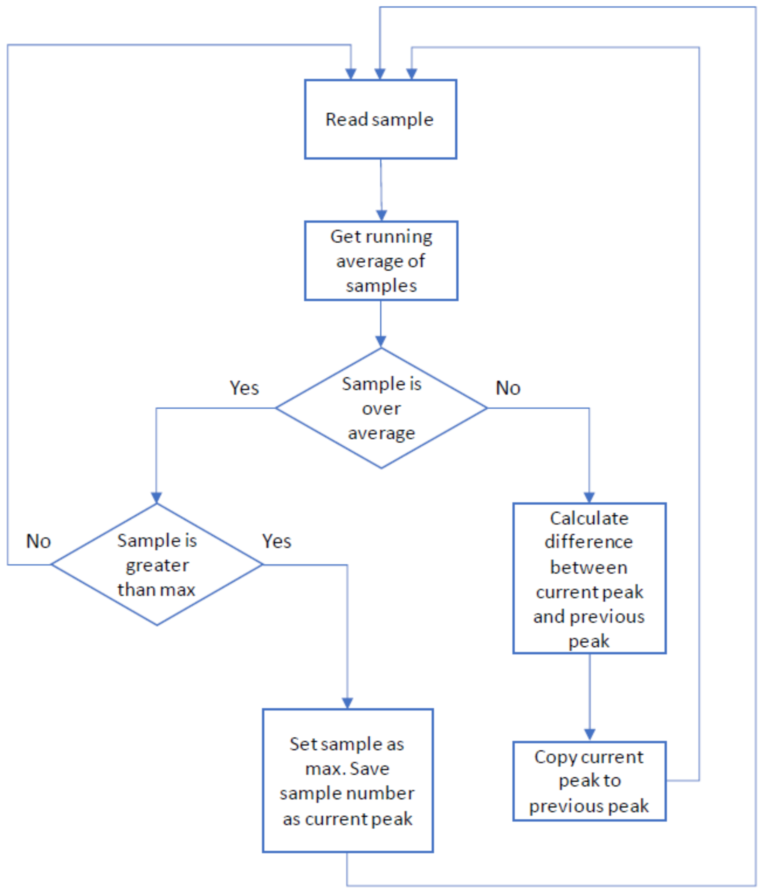


Figure 4. Algorithm for finding positive peak in PPG signal.

2.2.3 Finding peaks by slope inspection

For detecting peaks through slope inspection, much of the process regarding threshold and finding PPI and BPM remains the same as discussed in pervious methods. However, the algorithm to finding peak is changed. The slope is found out between the two successive sample values and the peak is calculated by determining the sample number which has a positive slope before the local maximum and negative after the maximum. This can be inferred through Figure 5. It can be observed from Figure 5 that the sample number which has positive slope with its previous sample and negative slope with its successive sample is the local maximum and can be regarded as the peak for the current interval.

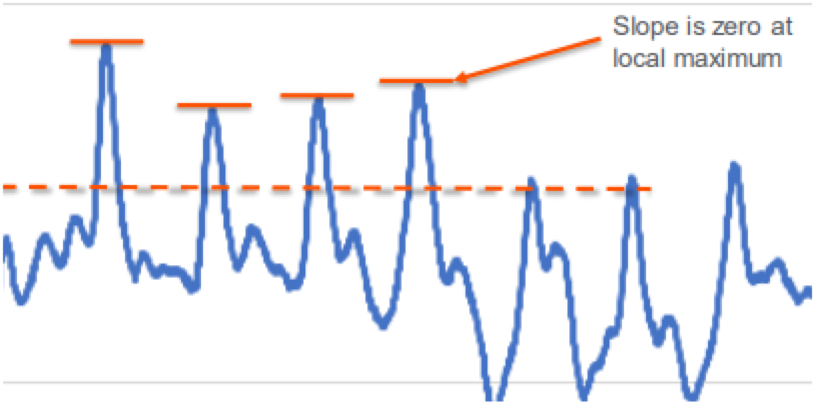


Figure 5. Slope Inspection Method for Peak Detection in PPG Signal.

3 Methods and Materials

There could be several approaches to solving a task and coming to the same conclusion. This holds to this project implementation as well. This chapter, therefore, provides ideas on modus operandi and materials utilized to reach the end goal of the project. Furthermore, information on the reason behind the methodological choices and descriptions of the hardware components, connections between them as well as software tools utilized are also presented.

3.1 Methodical choices

Among several ways of determining the heart rate and its variability photoplethysmography (PPG) was adopted for this project. PPG is an optical method that detects heart rate variability from body parts like fingers, wrists, earlobes, etc. The PPG signal is directly proportional to the quantity of blood flowing through the blood vessel which is associated with cardiac activity (Cheriyedath, 2019). The technical implementation usually consists of a setup of light-emitting diodes (LEDs) and optical detectors placed on a skin surface. Some of the light gets absorbed by the body tissue, especially the blood, and the rest is reflected to the sensor. The formulation of the results is based on the amount of reflected light measured by the detectors.

3.1.1 Familiarization with the components

The selection of the method and the components used in the project were predetermined by the school and the faculty staff. The added benefits of this method include a low cost, non-invasive measurement in action, and ease to use. The system was introduced in several phases in the form of lectures and proceeding assignments. Various components like LEDs, buttons, rotary knobs, OLED displays, and heart rate sensors were tested separately as well as in combination.

3.1.2 Heartbeat detection

A micro python script was prepared to read analog signals from the pulse sensor. The signals were read every 4 milliseconds using a hardware timer and stored in a ring buffer. Each value from the buffer was then read and printed in Thonny IDE's plotter view. This provided a visualization tool for the pulse detected as well as an affirmation of the sensor's functionality.

3.1.3 Heartrate detection

After the heartbeat was detected another script on top of the first one was prepared which also calculated the pulse rate. This script is based on the algorithm depicted in Figure 4 but uses the rising edge method instead of peak detection**.** At first, the script was tested on a set of data provided by the instructing teacher. The script was tuned up until the results were as close as the results provided for the same data set.

3.2 Materials

The core idea behind the project is based on a microcontroller called Raspberry Pi Pico W. The rest of the components and hardware are connected to this microcontroller to form the prototype. The connection between different components within the prototype and other devices in the system is presented as a block diagram in Figure 6. Similarly, a picture of the real setup of the components is shown in Figure 7.

The boundary of the prototype is marked within the dotted line. Communication between the components is shown with red arrows. While the communication of the prototype with a computer and the cloud server is shown in green and blue arrows respectively.

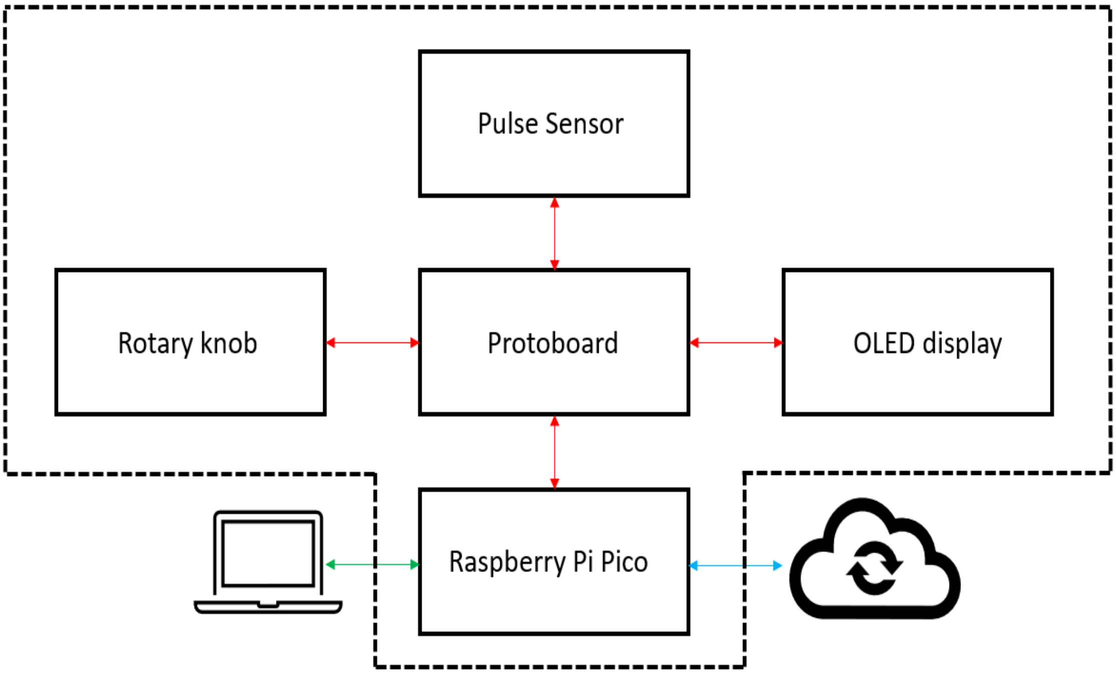


Figure 6: A simplified block diagram of the components

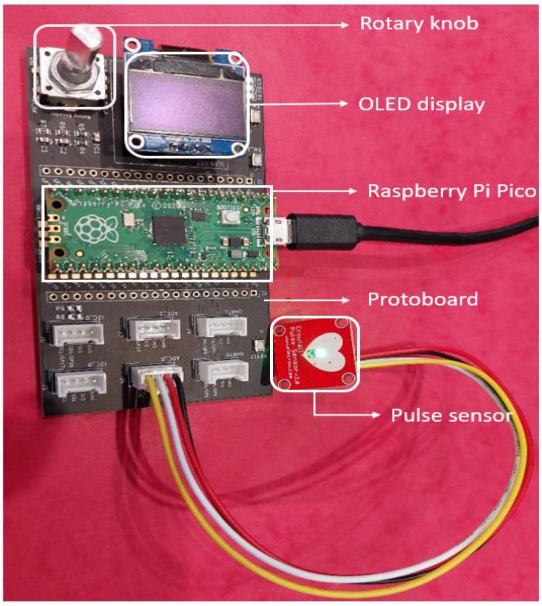


Figure 7: The prototype and its components

All the components are connected to the Raspberry Pi Pico W board via protoboard as shown in Figure 7. The prototype is connected to a computer via micro-USB in the Pico W board. The prototype can be connected wirelessly to the internet via WLAN (Raspberry Pi, 2023). A list of the components used in the prototype is presented in the following Table 2.

Table 2: List of the components used in the prototype.

Sn.	**Component**	**Description**	**More info**
1	Raspberry Pi Pico W	Dual-core ARM processor microcontroller having 246 kB SRAM and 2 MB on-board Flash. It also includes a 2.4 GHz wireless LAN and 26 multifunction GPIO pins.	[Raspberry Pi]
2	Crowtail Pulse Sensor v2.0	Optical heart rate sensor having LED, photodiode, analog amplifier, and	[Pulse Sensor 2.0]

		analog signal output. Operating voltage 3-5 V	
3	OLED display	SSD1306 compatible 128x64 monochrome organic LED display. Communicates with I2C or UART protocol.	SSD1306 OLED Using SSD OLED
4	Protoboard	Passive protoboard designed especially for this project to help connect other components to the Raspberry Pi Pico.	Joseph Hotchkiss, Project Engineer, Metropolia UAS
5	Rotary knob	Digital rotary knob with push button.	Joseph Hotchkiss, Project Engineer, Metropolia UAS

Hardware components barely do anything without proper software or codes to guide them to do what is aimed for. There are several software tools used in this project at various stages of the development phase. A list of the tools used is shown in Table 3.

Table 3. List of the software tools used in the project.

Sn.	**Tool**	**Application**	**More info**
1	Micro python	Programming language to code Raspberry Pi Pico	micropython.org
2	Thonny IDE	For writing the micro Python code	thonny.org
3	Kubios Cloud	Amazon Web Services (Using REST API interface)	kubios.com
4	Version control	Metropolia Gitlab	Group7_project

The programming language used in this project was micro python. Thonny IDE was used to write and test the Python scripts for the prototype. Kubios cloud service was used for further processing and interpretation of the data collected by the sensor. On a successful connection, a detailed HRV analysis was received from Kubios as a response. A version control system called Metropolia Gitlab is used for the collaboration of project codes between the team members.

4 Implementation

The implementation of the project guidelines can be divided into three broad sections namely: peak detection, HR and HRV analysis, and Navigation interface. The three sections do not encompass all the steps involved in the project. However, they define a major portion of the project working infrastructure and would include other aspects of the project within them. Further sections in this chapter would describe the mentioned sections in more detail along some snippets of the OLED screen.

4.1 Peak detection

Detecting peaks is one of the major steps in the project's overall functioning. However, detecting accurate peaks and peaks that are not manipulated or synthesized in any form is crucial for the reliable working of the embedded device. Peak detection process can be distinguished into three steps as shown in Figure 8.

Sample Data point → Detecting rising edge → Filtering the data

Figure 8. Peak detection algorithm.

To collect reliable information from the sensors in a periodic fashion which would provide enough data points to conclusively detect peaks, a hardware timer is used with a frequency of 250Hz. Meaning that ADC value from the sensor is received every 4 milliseconds irrespective of the functioning of the main program. These values received from the ADC converter are stored in a ring buffer which is of the length 750 i.e., a three second storage of the ADC values. The data points are read from the ring buffer and stored on a empty list which is then used for peak detection. This allows the ring buffer to act as a storage loop with new ADC values added every 4 milliseconds and previous values read as when required by the main program. This allows continuous data collection and storage without having to use the limited memory of the raspberry Pi Pico W.

The integer values received from the ADC converter when plotted on a graph shows something like a sinus wave function from where we can detect peaks and therefore calculate peak to peak interval. Considering a three second interval, the plotted graph should at least have two peaks i.e., a heart should beat twice in a three second interval even when it is at rest state.

An algorithm based on rising edge method to detect peaks is created which filters the data for noise and detects reliable peaks from the three second interval. The algorithm filters the data in a way that excludes extreme values from the data interval which may arise due to Movement artefacts (MAs) and Varying amplitude of the PPG signal.

4.2 HR and HRV analysis

Once a reliable list of peaks is determined from the peak detection algorithm, HR and HRV calculations are done by the program to present continuous heart rate value along with mean heart rate, mean PPI, time-domain HRV parameters (as root mean square of successive RR interval differences (RMSSD) which measures beat to beat variability and is strongly associated with the parasympathetic nervous system activity and standard deviation of RR intervals (SDNN), which is a measure of overall HRV, and reflects both sympathetic and parasympathetic nervous activity for an interval of at least 20 PPIs. These calculations are done locally by the program and the results are displayed continuously on the OLED Screen as in Figures 9 and 10.

Before diving into HRV analysis, it is essential to verify the accuracy of the results obtained from our prototype. This verification was conducted through two approaches. Firstly, the instructing teacher was consulted to ensure the validity of the outcomes. Secondly, a comparison was made with the results from a commercial fitness watch. To perform this comparison, a simple test was conducted, where both devices were used simultaneously to measure heart rate. The data collected by the prototype showed close alignment with the commercial product throughout the measurement, indicating the consistency and accuracy of our heart rate monitoring system. The results of that test can be found in Appendix 1.

Figure 9. Heart rate shown on OLED.

Figure 10. HRV analysis shown on OLED.

A deeper HRV analysis is also executed as requested by the user. To do this, Wi-Fi available on the raspberry pi Pico W is activated to send and receive data from the cloud services. The analysis is done through Kubios Cloud where data collected from the embedded device in the form of PPI list (at least 20 PPI values) is sent to the Kubios cloud system where PNS and SNS calculations are performed, and results are received back to the device and displayed on the OLED screen as seen in Figure 11. This action is performed once with no continuous data collection and analysis i.e., data is collected once for the displayed results.

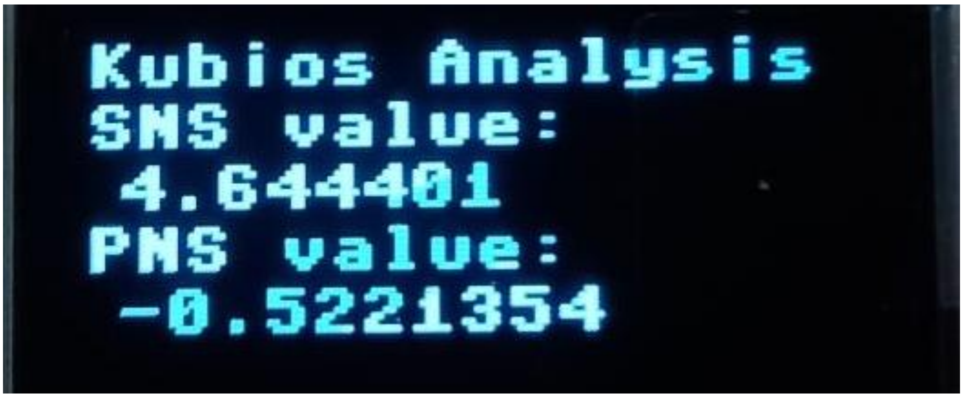


Figure 11. Kubios analysis shown on OLED.

4.3 Navigation interface

The embedded device is programmed with various functionalities as discussed in the previous section and would therefore require navigation which would enable the user to navigate through all available options and functionalities. This was achieved through the usage of a rotary encoder available on the embedded device. The encoder was programmed in a way that the rotation would select the menu options and pressing the encoder switch would let the user into the selected menu option. To exit the selected menu option the switch is pressed again, and the user comes back to the menu selection screen where he/she can navigate again into any of the options and continue infinitely without having to re-run the program or the embedded device again. The main menu that runs when the device is powered up can be seen in Figure 12.

Figure 12. Navigation menu on OLED.

5 Conclusions

The Conclusions section provides a summary of the project's outcomes and overall success in achieving its objectives. The key accomplishments are emphasized, and potential future improvements and optimizations that could enhance the embedded device's performance and broaden its applications are discussed.

In this study, we have explored the significance of heart rate variability (HRV) and the detection of peak-to-peak intervals (PPI) in photoplethysmography (PPG) signals. The analysis of HRV has been shown to be a valuable tool in assessing an individual's overall health and the balance between the sympathetic and parasympathetic nervous systems. We have discussed the factors that can affect heart rate, emphasizing the importance of understanding the individual variability and the influence of various external and internal factors.

Three different methods for detecting PPI in PPG signals were presented, highlighting the need for accurate pulse detection to ensure the reliability of HRV analysis. The choice of the most suitable method for PPI detection depends on the specific application and the challenges posed by the signal quality and the presence of artifacts. It is crucial to select an algorithm that can accurately detect peaks without missing critical information or including false peaks, which might skew the results.

The team successfully designed, implemented, and tested a heart rate monitoring system that effectively measures heart rate. Challenges such as pulse detection and threshold determination were addressed through deeper research and experimentation. The selected PPI detection algorithm demonstrated satisfactory performance in detecting heartbeats and calculating heart rate variability. Although the prototype has limitations, such as sensitivity to signal variability and lack of real-time continuous monitoring, it provides a strong foundation for further development and improvement. Future work could focus on enhancing the system's robustness to noise, implementing real-time continuous monitoring capabilities, and exploring potential applications in various fields, such as sports performance, stress management, and healthcare.

In conclusion, understanding the intricacies of HRV and accurately detecting PPI in PPG signals are essential for the development of reliable and effective health monitoring devices. The insights gained from this study can be applied to design and optimize algorithms and hardware for accurate HRV analysis and improved health assessment.

References

Cheriyedath, S. (2019, Feb 27). Photoplethysmography (PPG). Retrieved from news-medical.net: https://www.news-medical.net/health/Photoplethysmography-(PPG).aspx

Edward R., Laskowski, M. (2022). What's a normal resting heart rate? Retrieved May 1, 2023, from: https://www.mayoclinic.org/healthy-lifestyle/fitness/expert-answers/heart-rate/faq-20057979.

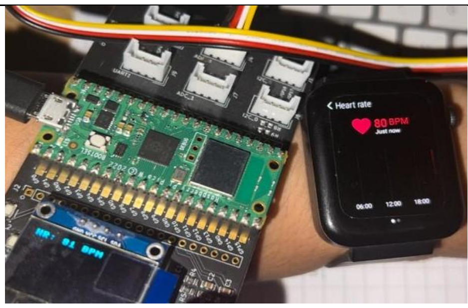
Metropolia University of Applied Sciences. (2023). Hardware Project. Espoo: Metropolia UAS.

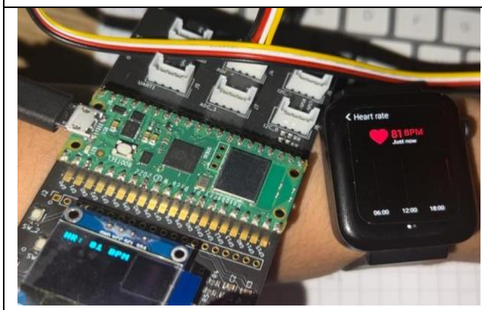
Raspberry Pi. (2023). Raspberry Pi Documentation - Raspberry Pi Pico and Pico W. Retrieved April 08, 2023, from: https://www.raspberrypi.com/documentation/microcontrollers/raspberry-pi-pico.html

Appendices

Appendix 1: Time lapse images and table comparing prototype results with a commercial product.

Graphical evidence when comparing results





Measured by our prototype		**Measured by fitness watch**	
Sec.	Heart Rate (BPM)	Sec.	Heart Rate (BPM)
1	74	1	75
2	75	2	75
3	73	3	74
4	73	4	74
5	75	5	75
6	76	6	75
7	75	7	76
8	75	8	76
9	77	9	77

10	76	10	77
11	77	11	77
12	78	12	77
13	79	13	80
14	81	14	80
15	80	15	79
16	81	10	79
17	80	11	81
18	81	12	81
19	82	13	80
20	81	14	80